

Animal Radioecology in the Exclusion Zone Since the Chernobyl Catastrophe

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Abstract: We review 20 year long investigations by the Schmalhausen Institute of Zoology on radioecological and ecological consequences of the Chernobyl catastrophe for wild animals in the Exclusion Zone (EZ) around the nuclear plant. Using previous observations on bird migrations through Ukraine, we assessed the ^{137}Cs and ^{90}Sr carry-out with migrants from the EZ. In addition, we selected animal species as standard indicators of the state of the environment to map: 1) contamination of vertebrates with ^{137}Cs in the EZ and 2) beta-activity of mollusc shells indicating ^{90}Sr , in the whole Dnieper drainage area, in the Kiev Administrative Region, and in the EZ. We revealed regular seasonal and long-term trends, relative radionuclide accumulation by different species, transfer and accumulation factors, and used these measurements to diminish the enormous variation and complexity of the data. Secondary ecological changes in forest, devastated by direct irradiation, were caused by the crash of trophic chains and an outbreak of insect pests on dead or sick trees. Ninety-nine percent of the EZ area was not affected directly by irradiation. Ecological changes in this area have been caused by evacuation of the public, cessation of agriculture and forest management, and decontamination on a large scale. After initial changes, animal density and distribution have been stabilized at a limit restricted by natural resources, predators and poachers. A herd of Przewalski horses was successfully introduced into the EZ years ago. We renewed the protected state of nature reserved sites, which existed before, and proposed to expand the area of nature reservation.

Key words: Chernobyl catastrophe; Radioecology; Bioindication

切尔诺贝利核事故以来隔离区动物生态的研究概况

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摘要: 综述了切尔诺贝利核事故以来乌克兰 Schmalhausen 动物研究所 (SIZ) 对核工厂周围隔离区 (exclusion zone, EZ) 的野生动物所进行的长达 20 年的放射生态学调查研究。基于乌克兰以往鸟类迁移的观察资料, 评估了 ^{137}Cs 和 ^{90}Sr 在隔离区候鸟体内的含量。而且还选择一些动物物种作为环境状况的标准指示生物, 目的是为了阐明: ^{137}Cs 在隔离区脊椎动物体内的污染情况; 整个第聂伯河流域、基辅行政区和隔离区软体动物贝壳内 ^{90}Sr 的 β 活性。结果表明不同物种相对放射性核累积、迁移和累积因素呈有规律的季节性和长期性变化趋势, 这些参数的运用可以大大地减少数据的波动和复杂性。直接辐射毁坏森林后, 营养链的崩溃和病死树昆虫害虫的爆发导致了其次级生态变化。99% 的隔离区并不直接受辐射的影响, 人员撤离、农业和森林管理停止以及大规模排除污染是这些区域生态变化的主要因素。在初始变化之后, 由于自然资源、捕食者和偷猎者等的限制, 隔离区的动物密度和分布达到一个稳定的极限值。数年前成功地在隔离区引入了一群蒙古野马, 该群体保持了稳定增长。重新评估了以前划定的若干自然保护位点目前的保护状况, 并提出了建议扩大这些自然保护区的范围等保护措施。

关键词: 切尔诺贝利核事故; 放射生态学; 生物指示

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On April 26 1986, one of four reactors at the Chernobyl nuclear power plant (CNPP) in North Ukraine exploded. About 3% of the active nuclear fuel

enriched with fission products was released into the atmosphere, causing extensive pollution to the neighbouring regions.

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The public within a 30 – 60 km radius of the site were evacuated. The depopulated area was announced as the Exclusion Zone (EZ) with restricted entrance. Description of the causes of the disaster, efforts to control it, patterns of the fallout and medical, economical, and social consequences of the catastrophe are out of the scope of this article.

Here we address only the ecological and radio-ecological aspects of zoological studies in the EZ, based mostly on original data obtained by the Schmalhausen-Institute of Zoology (SIZ). Ukrainian zoologists, with their knowledge of the baseline state of local wildlife, began measurements of radioactive animal products since two weeks after the catastrophe and started observations on the impact on animals directly in EZ from August 1986. Our investigations in the EZ and polluted regions span the 20 years since the disaster (Franzevitsch et al, 1994). The value of these studies includes:

1) evaluation of the radionuclide carry-out with migratory animals and possible danger to humans consuming the migrating game and fowl;

2) sampling of contaminated animals over the vast area as indicators of the state of the environment, first of all from the viewpoint of human safety;

3) recommendations on management of the abandoned natural territories in the EZ.

We refer predominantly to local sources of information, which are often ignored by Western science despite the unique understanding contained therein. Important radiological terms and units, necessary for understanding, are listed below.

Radionuclide—atom of a chemical element with the certain mass number, able to spontaneous decay or fission.

Activity—number of radioactive decays per unit time.

Bq—Bequerel, unit of activity, 1 decay a second; 1 GBq = 10^9 Bq; 1 TBq = 10^{12} Bq.

Ci—Curie, activity of 1 g of radium, 1 Ci = 3.7×10^{10} Bq; 1 MCi = 3.7×10^{16} Bq.

Specific activity—activity per mass unit (S_m , Bq/kg) or per volume unit (S_v , Bq/l).

Surface activity—activity in the soil per unit area (S_a , Bq/m²).

Accumulation factor—ratio between S_m in a biological material and S_v in the water.

Transfer factor— tf , ratio between S_m in a biological material and S_a in the soil.

Gy—Gray, unit of absorbed energy (dose) of ion-

izing irradiation, 1 Gy = 1 J/kg.

Sv—Sivert, unit of equivalent dose of irradiation, 1 J/kg, biological effect of gamma-rays, alpha- and beta-particles or neutrons taken into account.

Man-Sv—sum of individual equivalent doses for certain population.

1 Direct impact

Acute irradiation from the active cloud and the beta-emitting deposits heavily affected the immediate area of the disaster within a radius of 8 – 15 km.

The lethal injury zone (so called Red Forest, 5.8 km²) was characterized by the complete loss of Scotch pine (*Pinus silvestris* L.). The calculated absorbed dose for gamma-irradiation was equal to 80 – 100 Gy. In the sublethal injury zone (37.5 km², 10 – 20 Gy), a complete loss of young shoots of mature trees occurred. The intermediate zone (120 km², 3 – 5 Gy) was characterized by growth inhibition, loss of the growth points of coniferous species as well as development of radio-morphoses in 1987. The remainder of forests did not suffer radiation injury (Davidchuk et al, 1997).

The first expedition of D. Krivolutski (Moscow), while inspecting the nearest zone, 3 km south of the wreck in July 1986, was concerned only with soil samples. They revealed a reduction of litter arthropods. Numbers of shelly mites Oribatei and springtails Collembola were reduced by two orders, and there was a reduction in juvenile stages of earth-worms, compared to less polluted areas (Krivolutski, Pokarzevski, 1990). In September 1986, B. Testov and A. Taskayev (Syktyvkar) reported a 3 – 5-fold reduction of population density of rodents at a distance about 3 km from the wreck relative to control sites (1990).

2 Zoogenic radionuclide migration outside the EZ

Two issues were of immediate significance after the initial disaster:

1) Bird migratory lanes extend from as far as the Arctic shore to valleys of the Pripyat and the High Dnieper and concentrate at their confluence near the EZ.

2) Waterfowl are hunted down their migration route to SW Ukraine by about 300 000 registered hunters and comprised a direct route of radionuclides (RN) into the human diet.

The urgent task to assess zoogenic migration was posed in 1987. From previous observations of B. Sabinevsky (SIZ) we evaluated the biomass of the local

bird population in the EZ as 50 000 kg, and the migrant biomass as $5 \times 10^6 - 6 \times 10^6$ kg.

Post-catastrophic samplings of birds have been irregular and did not adequately represent all varieties of radioactive patches, diversity of biocoenoses and bird species due to sampling limitations. We proposed a generalized estimate of the RN transfer by birds, derived from the total biomass M of migrants, total area S of the EZ, total RN inventory A in the natural landscapes of the EZ, and the transfer factor tf of a RN from the soil to the biomass of birds. The population density per unit area is $p = M/S$. The share of the radioactive fallout in the open land, concentrated in the biomass of the given kind, is $a = p \times tf$. And, finally, activity in the migrant flock is $C = a \times A$.

The data used in calculation are given in Tab. 1. Inventory of RN in EZ is from Izrael et al (1987) and Kholosha and Sobotovitch (1994). It was corrected to 1988. Calculation of the transfer factor was based on radioactivity measurements in 107 samples of local birds, related to reported soil contamination with ^{137}Cs at the sampling site (Atlas of Chernobyl Exclusion Zone, 1996; Likhtarev et al, 1995). This upper limit of C ascribes migrants the same level of contamination as in local birds. The rate of zoogenic carry-out was certainly below 100 – 250 GBq (Frantsevich et al, 1992). This value is negligible compared to the rate of river carry-out, which was between 0.5 till 13 TBk of $^{134,137}\text{Cs}$ and 1.5 till 10 TBk of ^{90}Sr in different years (Derevets et al, 2004).

Tab. 1 Estimate of the radionuclide carry-out by bird migrants

Parameter	Parameter value for	
	Muscles	Skeleton
Radionuclide	^{137}Cs	^{90}Sr
tf , transfer factor (m^2/kg)	0.0095	0.0107
M , total biomass of migrants (kg)	5×10^6	
S , area of the EZ (m^2)	2.5×10^9	
p , biomass density (kg/m^2)	0.002	0.002
a , share of inventory in the zoomass	1.9×10^{-5}	2.1×10^{-5}
A , inventory inside the 40 – km circle (MCi)	0.36	0.085
A , inventory inside Ukrainian part of EZ (MCi)	0.11	0.127
C , carry-out by migrants (Ci/year)	6.8 – 2.1	1.8 – 2.7
Same (GBk/year)	250 – 75	67 – 100

Game birds comprise about 15% of the total migrant biomass. About 3.3×10^6 kg of birds, among them over one million ducks, were shot in the populated regions of Ukraine covered by migratory lanes in 1995 (Main Indicators of Hunting in Ukraine During 1994, 1995). About 3×10^5 kg of this total have presumably migrated through the EZ.

The highest estimate of ^{137}Cs , consumed in the meat of hunted birds, was 4 – 12 GBq per year, that yields the equivalent collective dose for consumers as 50 – 150 man-Sv. During the ten years since the disaster, water-soluble ^{137}Cs in the river water and in the soil diminished by 5 – 10 times (Wojcechowicz et al, 1996; Arkhipov et al, 1996), and contamination of fish also diminished by ten times (Vovk et al, 1966; Ryabov & Belova, 1996). Hence the lowest estimate may be 10 – 100 times lesser than the highest one.

3 Contaminated animals as indicators of contaminated environment: ^{137}Cs

We investigated contamination of ungulates with

^{137}Cs within an area of 85×65 km, mapped for the Atlas of the Chernobyl Exclusion Zone. The goals were to show all records of wild boar (*Sus scrofa* L.), roe deer (*Capreolus capreolus* L.), elk (*Alces alces* L.), and red deer (*Cervus elaphus* L.), totally 436 sampled in the mapped area, and to use these data, after necessary generalization, for prediction of animal contamination elsewhere within this area.

Such prediction is possible on the base of better known soil contamination. The inevitable error of prediction is caused by variation of animal radioactivity, which is enormous due to the patchiness of the pollution, species diversity, seasons and years of sampling, unpredictable individual migrations of hoofed beasts. We attempted to diminish the error using some reliable regularities in ^{137}Cs accumulation (Tab. 2).

Seasonal change of ungulate contamination depends on seasonal diet, which was similar in Ukraine and Germany, but differed from that of the wild boar at the Savannah River Site in South Carolina (USA). The difference could be due to difference in latitude(20°),

Tab. 2 Relative in ¹³⁷Cs accumulation by vertebrates

Character of accumulation	Locality	Species	Regularity	Reference
Annual cycle	Chernobyl	Roe-deer	7.1 times higher in October than in April	Original, SIZ
	SW Germany	Roe-deer	Maximal in October	Wolf, 1990
	Chernobyl	Boar	3.9 times higher in February than in August	Original, SIZ
	South Carolina	Boar	Maximal in the summer	Stribling et al, 1986
Temporal trend	Chernobyl	Ungulates	Not revealed	Original, SIZ
	Chernobyl, USA	Fresh-water fish	Ecological half-life 3 – 7 years	Nasvit et al, 1997; Vovk et al, 1996; Brisbin et al, 2002
Individual	Chernobyl	Boar, roe-deer	134% and 105%	Original, SIZ
Variation V	SW	Germanyroe-deer	60% – 140%	Wolf, 1990
Transfer factor	Chernobyl	Boar	0.021 m ² /kg	Original, SIZ
	Belarus	Ungulates	0.036 m ² /kg	Kenigsberg et al, 1996
	SW Germany	Roe-deer	0.02 m ² /kg	Wolf, 1990
Species to species ratio	Chernobyl	Predatory fish to omnivorous fish	3.3	Shevtsova and Voronovich, 1995; Nasvit et al, 1997; Vovk et al, 1996
	Russia	Terrestrial animals to hydrobionts	4 – 5	Ilyenko and Krapivko, 1989
		Boar/roe deer	0.24	
	Chernobyl	Boar/elk	1.53	Original, SIZ
		Boar/red deer	1.18	

climate, vegetation, relief, and local seasonal migrations. Note that contamination changes by times during the year. One can express the annual cycle by a plot, a table, or a formula. Knowing contamination level at some standard date (set on October 1, 1996 in the Atlas), we are able to predict average contamination of the given species hunted on arbitrary day.

Individual variation was determined for samples collected within the same area (about 100 km² for hoofed beasts). The variation coefficient is $V = 100\% \sigma / m$, where m is the mean, and σ is the standard deviation. Typical asymmetric distribution within a large sample of the wild boar is depicted in Fig. 1. Variation puts limits for reliable prediction and outlines the scatter of probable contamination values for a given locality. We constructed a nomogram for the known m and V , which returned the percentage of specimens contaminated above a given level (Frantsevich & Ischuk, 2000).

Radioactive contamination of animals was directly proportional to the soil contamination. In Fig. 2, ¹³⁷Cs in the muscle tissue of the ungulates is plotted versus contamination of the soil. The ratio between the specific activity in the tissue and the surface activity in the soil is the transfer factor, tf , also indicated in Tab. 2. Like values of tf were reported for different localities in post-

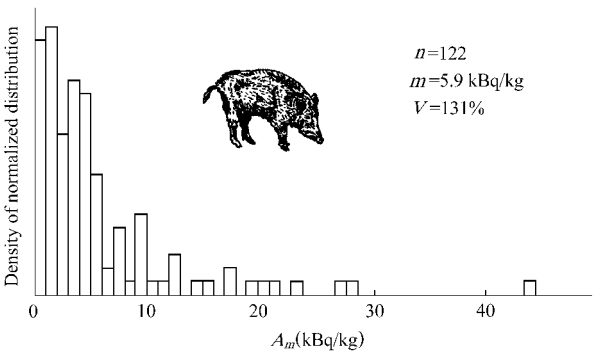


Fig. 1 Distribution of the specific activity A_m of ¹³⁷Cs, in the muscle tissue of a boar, *Sus scrofa*. n is number of samples, m is the mean, V is the coefficient of variation (m/σ). Measurements from a hunting forestry, 45 km south of CNPP

Chernobyl Europe. Deriving the transfer factor from hundreds of animal samples, we can extrapolate the anticipated animal contamination for any locality with the aid of much more detailed map of soil contamination, derived from many thousand soil samples. Thus we obtained the continuous map of animal contamination. The number of variables, imaged on the map, was greatly reduced from four ungulate species to only one standard species, the wild boar, and from several seasons or months to the single standard date, October 1. Data de-

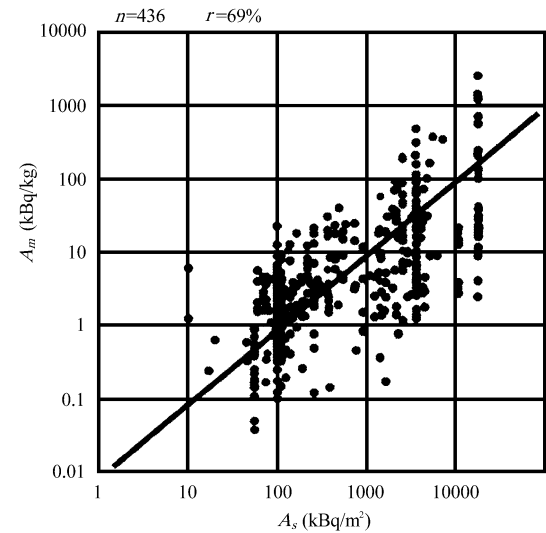


Fig. 2 Relationship between ¹³⁷Cs soil contamination A_s , and contamination A_m , of the muscle tissue in hoofed animals, after removal of the seasonal trend and data reduction to the standard species, the boar. The straight line shows unbiased proportionality

compression is easily computed with the aid of seasonal cycles and interspecies ratios of accumulation stated in Tab. 2.

The permissible level of ¹³⁷Cs contamination in the meat is 200 Bq/kg (State Hygienic Norms, 1997). Only 8% of the mapped area seemed to be safe for hunting. We regard the state of the wild animals as a model of possible contamination for people living in the same area and consuming local produce without any restrictions.

Tab. 3 Relative accumulation of ⁹⁰Sr, assessed by shell beta-activity, in mollusc genera (325 pairs of genera sampled at the same site in EZ or in polluted areas of Europe)

Genus	Relative accumulation	Genus	Relative accumulation
<i>Lymnaea</i>	1.0000	<i>Dreissena</i>	1.7879
<i>Planorbarius</i>	0.9900	<i>Cepaea</i>	6.3613
<i>Viviparus</i>	1.0050	<i>Bradybaena</i>	6.5189
<i>Anodonta</i>	1.5921	<i>Succinea</i>	3.5932
<i>Unio</i>	0.9930	<i>Helix</i>	22,36

Specific beta-activity in 65 shell samples from 25 water bodies within the EZ was compared to the published data on ⁹⁰Sr activity in respective water bodies (Wojcechowicz et al, 1996; Panasevich et al, 1998; Fig. 3). We evaluated the accumulation factor as 3777. The transfer factor of ⁹⁰Sr versus its surface activ-

4 Contaminated animals as indicators of contaminated environment: ⁹⁰Sr

Molluscs have often been used for tracing environment contamination with heavy metals (Williamson & Evans, 1972; Beeby & Eaves, 1983) and RN (e. g. Nelson, 1962; Kuzmenko et al, 1990; Gaso et al, 1995). The natural activity of shells (70 – 150 Bq/kg) is due to the natural isotope ⁴⁰K. Molluscs selectively accumulate ⁹⁰Sr in their shells. Even in samples from the western track of the Chernobyl fallout, where ¹³⁷Cs prevailed over ⁹⁰Sr, 92% of the shell beta-activity was caused by ⁹⁰Sr/Y. Shell radioactivity in post-Chernobyl Ukraine is 2 – 4 orders of magnitude greater than the natural background. Selectivity to ⁹⁰Sr allowed direct beta-radiometry of shells instead of radiochemical separation. This express method is simple and cheap in its analytical part, but sensitive enough to detect the biologically active environment contamination.

Our collection of mollusc shells consists of 1250 samples from Ukraine, Belarus, Russia etc. Many samples included several species of ten mollusk genera. We used the same reductionist approach for data compression as described above. Tab. 3 shows that beta-activity may vary up to 20 times depending on the genus. Recalculation of all measurements to the standard species, a pond snail *Lymnaea stagnalis* L., halved initial variability of measurements. Temporal trend was calculated using 32 pairs of replicated samples at the same sites in 1988 – 1994 and 1997. The ecological half-life was 11.6 ± 3.0 years.

ity in the soil was 0.12 m²/kg in the terrestrial and local freshwater mollusks within the EZ. Inverse dependence of accumulation on the free calcium content in the soil solution and local water-bodies was confirmed.

Individual variation was measured in highly radioactive specimens collected within the small home-

range of about 100 m². The variation coefficient (*V*) in freshwater molluscs was 10% – 30%, whereas in terrestrial snails it was 20% – 60% (Frantsevich et al, 1995), much less than in hoofed animals mentioned above (Fig. 4).

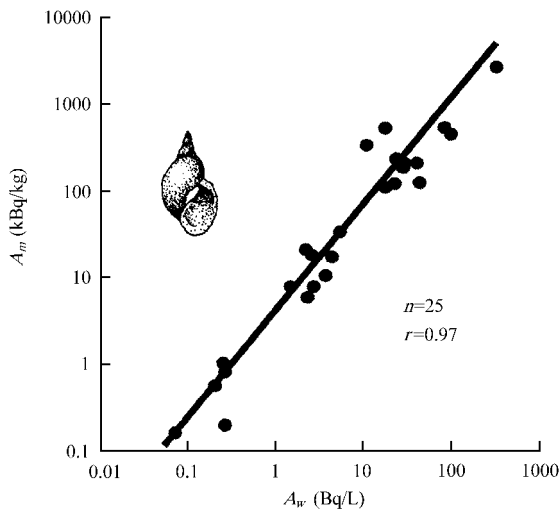


Fig. 3 Direct relation between ⁹⁰Sr concentration in the water (*A_w*) in the water bodies of the EZ and specific beta-activity of mollusc shells (*A_m* standardized to the pond snail)

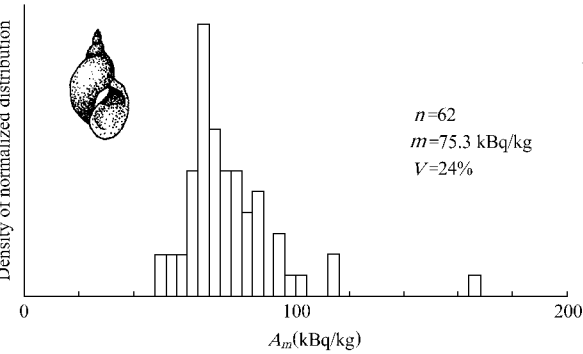


Fig. 4 Distribution of the specific beta-activity *A_m* in the individual shells of the pond snail *Lymnaea stagnalis* (homogenous sample from a creek 5 km south of CNPP). *n* is number of samples, *m* is the mean, *V* is the coefficient of variation (*m*/*σ*)

We implemented biomonitoring of the river Dnieper and its numerous tributaries in 1990 – 1991. The drainage area of the Dnieper is 500 000 km². Fifty rivers were sampled at 267 sampling points. In the following year, we inspected the contamination with ⁹⁰Sr in the Kiev Region (29 000 km², 379 sampling points). The EZ itself and its surrounding area (85 × 65 km) was represented by 174 sampling sites (Frantsevich et al, 1996).

The highest levels of shell contamination (3 560 – 1 070 kBq/kg) were found in the small lake, 4 km N of the reactor wreck. Using the value of the accumulation factor, we derived that, for the permissible level of 2 Bq/l of ⁹⁰Sr concentration in the water (State Hygienic Norms, 1997), the critical beta-activity of pond snail shells must be 7.5 kBq/kg. If beta-activity of the standard *Lymnaea* shell exceeds the critical level, then the state of environment is undesirable to the public. Outside the EZ, we obtained only five samples with the overcritical activity: 9 – 49 kBq/kg at the distance 30 – 70 km from CNPP.

5 Secondary ecological changes in the lethal injury zone

During the first three years after the loss of pine, microarthropods in the forest litter recovered. However, their species diversity diminished (Krivolutski & Pokarzewski, 1990). The number of dead and sick pine trees provided a mass outbreak of insect pests. They peaked in 1989, but already in 1991 survived trees were only slightly infected (Lindeman, 1990).

Trophic chains in the environment were destroyed. Phytophagous insects were deprived of food and their elimination led to the disappearance of insectivorous birds. Bird song count by M. Voinstvenski (SIZ) in 1987 May revealed up to six pairs per hectare of five species nesting among dead trees: the wryneck (*Jynx torquilla* L.), spotted flycatcher (*Muscicapa striata* Pall.), chaffinch (*Fringilla coelebs* L.), tawny pipit (*Anthus campestris* L.), white wagtail (*Motacilla alba* L.). Their quantity was 4 – 5 times less than at the control lots of the healthy pine forest or at the patches of green trees in the sublethal injury zone (Balashev et al, 1992).

European hares (*Lepus europaeus* Pall.), foxes (*Vulpes vulpes* L.), residual domestic dogs, and rodents permanently penetrated the Red Forest from the neighbor areas. In March 1987, we discovered footprints of mice and hares at the most contaminated forest site near the CNPP fence. At that moment, the dosage rate above the deep snow was about 10 – 15 mSv/h. Arenae above the buried forest were permanently visited by hoofed beasts (wild boar, elk, roe deer) and wolves (*Canis lupus* L.). Their visits were confirmed by tracking and occasional encounters.

In the summer of 1987, the number of rodents recovered due to migration, which was confirmed by radiometry; migrants were too clean to have originated at the site of capture (Testov & Taskaev, 1990).

6 Secondary ecological changes due to change in human activity

One hundred and thirty-five thousand people and 35 thousand cattle were evacuated from the 30 km wide circle around CNPP. Their direct pressure over bio- and agrocoenoses of the EZ is easy to calculate: 3 200 and 6 000 – 7 000 kg, respectively. These values exceeded population density of big mammals by hundred times and density of rodents or birds by fifty times. Crop were left in the fields, industrial forestry was ceased and recreation overload on natural lands was removed. After removal of competitors (man, cultivated plants, domestic animals) favorable conditions arose for weeds, wild-growing plants, and wild animals.

Care of the forest was neglected for several years. From year to year, snags accumulated, blocks and vistas were rubbished with dead wood, uncontrolled foci of insect pests emerged. As a result, during the dry season of 1992, catastrophic fires caused by arsonists annihilated 170 km² in the Ukrainian part of the EZ. Earlier, in 1987, protective dams built in the drainage channels (in a vain attempt to prevent RN migration) flooded and destroyed 20 – 30 km² of the forests on lowlands. Biocoenotic losses caused by lethal irradiation comprised as low as 3% – 5% of the losses due to irrational activity of a man.

In 1987, a mass outbreak of rodents was observed on fallow lands of the EZ by V. Gaichenko (SIZ). Before the catastrophe, rodent density did not exceed 20 – 30 specimens per hectare. The dominant species were the common vole (*Microtus arvalis* Pall.) and the house mouse (*Mus musculus* L.). The common field mouse and the striped field mouse (*Apodemus silvaticus* L., *A. agrarius* Pall.) occurred more rarely.

During 1986, the density of rodents at the reference field, 5 km south of CNPP, did not exceed 30 per hectare, and 10 – 20 per hectare in April 1987. However, with the beginning of the reproduction period, the number of mice rose dramatically. At mid-summer, the density of the common field mouse and common vole was already 600 – 700 per hectare, and by October it approached 2500. Yet in December there was significant reduction back to 750 per hectare. Upon such a high residual density, the forage available for wintering rodents was enough for only 1 – 2 months.

The number of birds of prey (falcons, hawks, harriers, owls) were attracted to such rich hunting land: their density over the fields was several specimens per 1 km².

Mass elimination of the rodents occurred during the winter 1987 – 1988. In April and May 1988, surveys at the reference field revealed only the common vole (80 – 100 per hectare). By September, the density was again twice reduced. The outbreak and the following extinction proceeded similarly at the territories with high and low contamination levels. In 1989 – 1990, density was stabilized at the level of 100 – 180 per hectare.

Spatial distribution of wetland birds was abruptly disturbed in 1987, when construction of protective dams caused formation of shallow ponds, attracting water fowl. The total quantity of ducks (*Anas platyrhynchos* L., *A. querquedula* L.) and coots (*Fulica atra* L.) at these ponds in the EZ was assessed by aerial observation in the summer as 15 000 – 20 000 individuals, then twice as much at the beginning of the autumn, and up to 50 000 – during peak migration. In the autumn of 1987, the temporary ponds were destroyed since they were useless. By 1989, the density of nesting bird population was reduced by ten times (data of A. Mikityuk, SIZ).

Since the catastrophe, large beasts reproduced to the limit restricted by natural resources, pressure of predators and poachers. According to the averaged data of the ground and aero-visual estimations in the Ukrainian (Balashev et al, 1992) and Belarussian (Suschenya et al, 1995) parts of the EZ, density (per km²) was estimated for wild boar as 2 – 6; European hare < 1; elk 0.5 – 1; roe deer and fox 2 – 3. Beavers (*Castor fiber* L.) also successfully colonized abandoned drainage channels.

Wolves were not numerous before the catastrophe. During the following years, these beasts increased by several times and at present are evaluated as over 100 specimens in the whole EZ. Rare predators: the bear (*Ursus arctos* L.) and the lynx (*Lynx lynx* L.)—sometimes appear in remote refuges of the EZ.

7 Management and reservation of the EZ

Natural areas of the immediate zone, directly affected by the radiation impact, comprise less than 1% of the total area of the EZ. Events in the remaining 99% are determined by normal ecological laws, taking into account removal of the anthropogenic pressure from the most part of the area and engineered decontamination activity. Conditions in the EZ resemble a sort of natural reserve. After many unsuccessful attempts at large scale decontamination in forests and fields, it has been recognized that the best way to fix the RN fallout within the EZ is the natural flourishing of solid multi-

component biocoenoses.

Twelve natural reservation sites existed at the EZ before the catastrophe. Their total area comprised 23 km², a rather small percentage of the abandoned area. These sites were reexamined (with our participation) in 1994 and came under responsibility of the Administration of the EZ (Balashev et al, 1996). Long-lasting observations revealed 16 animal species of the Red Data Book of Ukraine (Balashev et al, 1999) within the EZ.

The enthusiastic attempt of SIZ (V. Kryzhanovskii, M. Samchuk) to introduce the wild Przewalski horse (*Equus przewalskii* Poljakov) from the excess in the Askanya-Nova Reserve in 1998 appeared to be astonishingly successful. Now several herds, accounting over 80 horses, live in the laylands. They partly compensate the absence of native hoofed beasts, which graze the grass in the fields and facilitate recovery of forest vegetation, prevented now by the dense layer of grass. Without intervention, the natural renewal of the forests would be dragged for decades (Didukh et al, 1993; Frantsevich et al, 1997).

We propose criteria for a new reservation in EZ:

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- 2) valuable and stable compact stands of deciduous and mixed forests;
- 3) vast laylands with natural succession of vegetation;
- 4) wetlands hosting local and migratory birds; and
- 5) that sites do not interfere with decontamination projects and with the slightly polluted part of the EZ which may be repopulated (Frantsevich & Balashev, 1999).
- The efforts of establishing a new reservation are now in progress.
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